New Developments Are Improving Flexor Tendon Repair

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Summary: New developments in primary tendon repair in recent decades include stronger core tendon repair techniques, judicious and adequate venting of critical pulleys, followed by a combination of passive and active digital flexion and extension. During repair, core sutures over the tendon should have sufficient suture purchase (no shorter than 0.7 to 1 cm) in each tendon end and must be sufficiently tensioned to resist loosening and gap formation between tendon ends. Slight or even modest bulkiness in the tendon substance at the repair site is not harmful, although marked bulkiness should always be avoided. To expose the tendon ends and reduce restriction to tendon gliding, the longest annular pulley in the fingers (i.e., the A2 pulley) can be vented partially with an incision over its distal or proximal sheath no longer than 1.5 to 2 cm; the annular pulley over the middle phalanx (i.e., the A4 pulley) can be vented entirely. Surgeons have not observed adverse effects on hand function after judicious and limited venting. The digital extension-flexion test to check the quality of the repair during surgery has become increasingly routine. A wide-awake surgical setting allows patient to actively move the digits. After surgery, surgeons and therapists protect patients with a short splint and flexible wrist positioning, and are now moving toward out-of-splint freer early active motion. Improved outcomes have been reported over the past decade with minimal or no rupture during postoperative active motion, along with lower rates of tenolysis. (*Plast. Reconstr. Surg.* 141: 1427, 2018.)

Outcomes of primary flexor tendon repair in zone 2 in the digits have long been unpredictable. However, an increasing number of surgeons have reported much-improved outcomes in this area in recent years. Over the past two decades, several surgical techniques have been established as essential or even critical to tendon repair in the fingers and thumb. The most important are strong core suture techniques, judicious venting of the annular pulleys, evolution of early active motion regimens, and recognition of key principles in surgery and rehabilitation,[1–11] which have substantially changed the landscape of digital flexor tendon repair. Recently, improved outcomes have been demonstrated not only by well-established hand centers but also by surgeons with mid-level expertise in tendon repair.[10–22] This article reviews developments in techniques of surgery and rehabilitation critical to improving outcomes.

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RECENT REPORTED OUTCOMES

One notable change in outcomes is the decrease in rupture rates after zone 2 flexor tendon repairs.[10–20] A review of the reports in leading hand and plastic surgery journals over the past decade indicates only 0 to 5 percent rupture rates,[10–22] and a few recent reports had zero ruptures in 50 to 100 repairs.[12,14–16,19,21,22] With regard to functional recovery, reports in recent years reflect overall excellent and good rates greater than 80 percent.[12–16,19] Notably, use of weak core sutures, rehabilitation with use of rubber-band traction,

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or failure to incorporate active digital flexion produce fewer outcomes considered excellent or good.[23] I direct readers to recent reports in which the key technical points, such as strong repair techniques, venting the pulleys, and early active motion were incorporated into surgical repair and rehabilitation; these reports bring us closer to the long-expected goal of more predictable outcomes of zone 2 tendon repairs and satisfactory outcomes in a majority of patients.[12,14–16,19,21,22] The authors of these reports do not consider that expected outcomes are harder to achieve in zone 2 than in other areas, although many more technical details than those in other zones should be attended to, and repair surgery should be as meticulous as possible and rehabilitation more carefully designed and executed.

STRONG CORE SUTURE METHODS

Strong core suture methods emerging in the 1980s and 1990s are now used widely. Strong surgical repairs are currently achieved through various multistrand methods. Recently developed or clinically used multistrand repairs are exemplified in Figure 1. Such strong repairs are intended to minimize risk of rupture during early active digital motion. Because active digital motion without resistance generates 0 to 30 N of force over the flexor tendons,[24] it is generally believed that a four-strand core suture (with 4-0 or 3-0 nonabsorbable suture) is a minimum requirement. However, a six-strand core suture would make the repair safer, and some surgeons even use eight or more strands. Currently, a four-strand repair is the most popular,[6,7] but I use a six-strand repair.[1,5,6] A four-strand repair meets basic requirements regarding repair strength. However, because less-experienced surgeons frequently perform these repairs, certain safety measures should be observed; an easy approach is to increase the number of suture strands from four to six. I observed that after completion of a four-strand repair, the repair site usually has remarkable pliability, and gaps on stretching; however, after placing two additional strands, the repair site shows much greater firmness and resistance to gapping when pulled. I always perform a six-strand repair in zone 2. Eight or more strands is reasonable but is used by fewer surgeons or in special cases requiring a more robust repair.[25]

In making a core suture, it is critical to keep its purchase of at least 7 to 10 mm in each tendon stump (Fig. 2).[26–28] The lock size should be 2 mm in diameter if a locking suture is used. A 4-0 or 3-0 nonabsorbable nonbraided suture, regular monofilament nylon, or a looped nylon such as Supramid Extra (S. Jackson, Inc., Alexandria, Va.), depending on repair methods, is used in tendons in the digit area of my patients. (**See Video, Supplemental Digital Content 1**, which demonstrates how to make a six-strand M-Tang repair using two looped nylon sutures, available in the "Related Videos" section of the full-text article on PRSJournal.com or, for Ovid users, at ***http://links.lww.com/PRS/C771***.) I do not favor Ethibond (Ethicon, Inc., Somerville, N.J.) suture in zone 2 repair, because it is hard to keep under tension and easily becomes loose. FiberWire (Arthrex, Naples, Fla.) is too rigid for making a smooth tendon repair in zone 2, but Ethibond or FiberWire can be used in the forearm. I prefer a needle of a larger size, but have no particular preference regarding needle types. Leaving suture knots outside the tendon or burying them between the tendon ends is not a major consideration. In my repairs with an M-Tang method, knots are exposed on the tendon surface, most on the lateral aspects of the tendon.

JUDICIOUS VENTING OF ANNULAR PULLEYS

Most hand surgeons now agree that critical annular pulleys can and should be vented during primary repair to allow freer tendon gliding.[21,22,29–33] Although it was not acceptable 20 years ago, this practice is now considered critical to ensure functional recovery and is unlikely to cause clinical problems when executed cautiously.[21,22,29,31] Narrow and rigid annular pulleys restrict tendon gliding and block motion of the edematous tendon repair site. Therefore, release of these pulleys (or their most narrow parts) is key to improving tendon motion, decreasing risk of rupture during early active digital motion.[29,32–34] Nevertheless, such releases should be executed cautiously to avoid creating a lengthy sheath-pulley defect and damaging the series of annular pulleys. The flexor pulley system is intricate yet robust to some loss of integrity; losing a portion of the sheath-pulley does not affect digital function. The pulley release does not need to be lengthy, because in the proximal part of a finger of an average adult, the flexor tendons glide only 1.5 to 2 cm with full digital extension and flexion.[21,22] Therefore, release of the sheath and pulley shorter than 2 cm is sufficient to allow the tendon to glide for the entire range of finger flexion. A sheath-pulley release less than 2 cm long causes no clinical tendon bowstringing, provided that other sheath and pulleys are preserved.

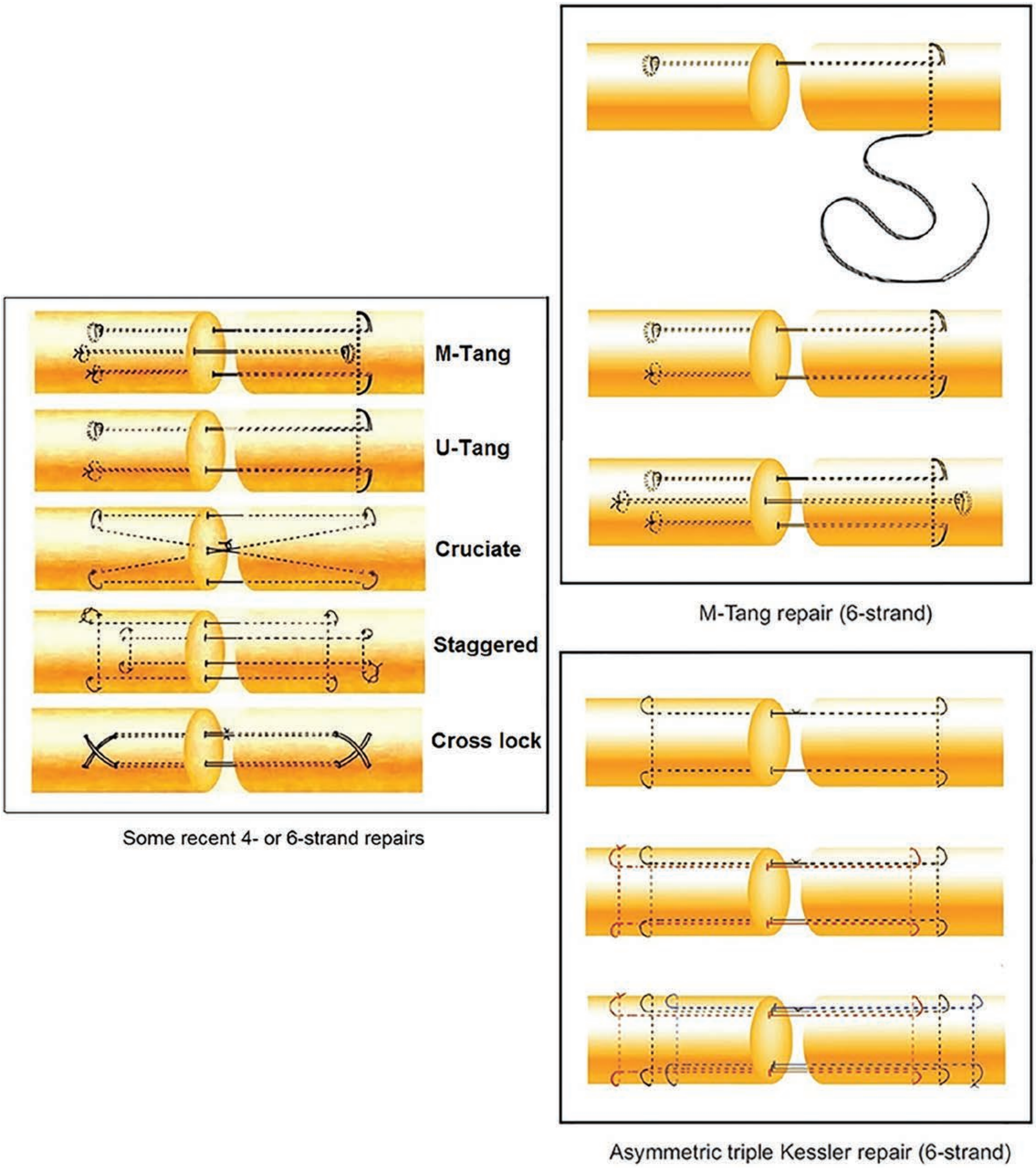

Fig. 1. A few recently developed or commonly used four- or six-strand repair methods. (*Left*) Summary of a few repair configurations and designs. (*Above*, *right*) Details of methods of making a six-strand M-Tang repair using looped monofilament nylon. Note that two looped sutures are used. (*Below*, *right*) Asymmetric triple Kessler repair is shown. Three groups of Kessler repairs can be used to make a six-strand repair. If only four groups of Kessler repairs are used, the repair method is called a four-strand Kessler repair, a popular four-strand repair used by many surgeons. The U-Tang method is a four-strand repair (shown below M-Tang on the *left*), which omits two strands of the M-Tang repair.

Correctly incising a segment of sheath and pulleys while avoiding damage to tendon function demands a profound mastery of anatomy.[1,6,7] Two essential rules are as follows: (1) a segment of the A2 pulley should always be retained (the venting can be distal or proximal to the retained A2 portion, which may include the entire A1 pulley or cruciate pulleys distal to the A2 pulley); and (2) the A4 pulley can be entirely vented, including extension to the A3 pulley, but should not extend over or much proximal to the A3 pulley. Occasionally, the A2 pulley will have to be entirely vented, but this is not customary. Retaining at least a part—up to one-half or two-thirds—of the A2 pulley is a safe recommendation for venting.[1,6,7,21]

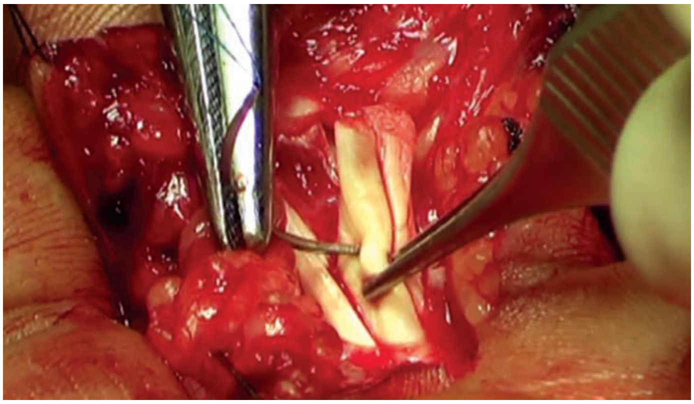

Fig. 2. It is critically important to keep sufficient core suture purchase in the stump. Note the bite on the stump should be 0.7 to 1 cm away from the cut site as shown in the photograph.

Video 1. Supplemental Digital Content 1, which demonstrates how to make a six-strand M-Tang repair using two looped nylon sutures, is available in the "Related Videos" section of the full-text article on PRS-Journal.com or, for Ovid users, at ***http://links.lww.com/PRS/C771***.

Again, proper venting of pulleys is based on mastery of their locations and identification of the pulleys intraoperatively. Surgeons should familiarize themselves with the anatomy involved before surgery. Understanding the intricate anatomy of the pulleys may be easier said than done, but this is key to performing a correct venting procedure.

TENSION ACROSS THE REPAIR SITE WITH SOME BULKINESS

If I were asked to name three keys to an ideal repair, I would respond, "strong core suture repair, venting of pulleys, and tension over the repair site." Clinically, tension-free tendon repair is harmful. Maintaining tension across the suture strands increases the ability of the repair to resist gapping during active finger flexion.[35] Tension across the repair site is also vital to preventing repair rupture. If a surgeon performs a core suture repair with four or six strands, but without sufficient tension, the repair will easily gap and disrupt at the junction of the tendon ends. If the tendon is not loaded during surgery, gapping may not be noticed by surgeons. However, once loaded, if gapping occurs, the repair tends to disrupt (Fig. 3). Therefore, we need to ensure sufficient tension in the suture strands and allow some tendon bulkiness.[21,35]

Adding tension across the repair increases tendon bulkiness but, in current practice, appears not to be a major issue, because the constrictive or narrow pulleys are vented and tendon repair-site bulkiness lessens when the tendon is loaded proximally.[34,35] The allowable repair-site bulkiness in terms of tendon diameter is 120 to 130 percent of the uninjured tendon in my practice, which

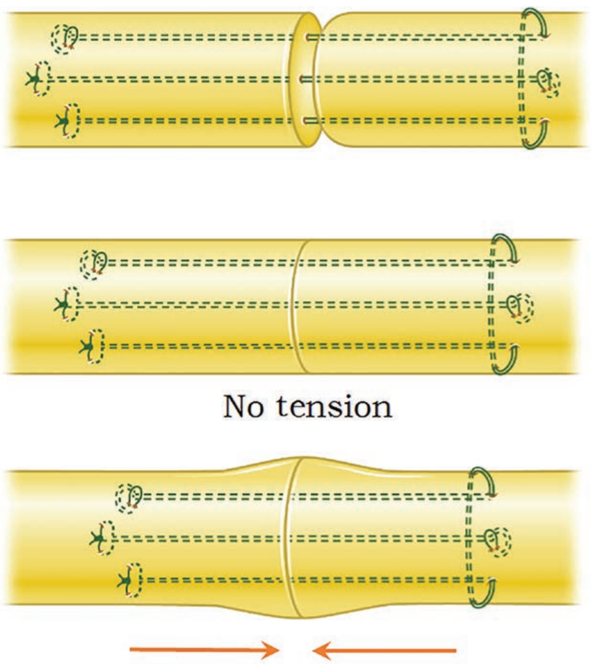

Fig. 3. Bulkiness versus tension across the repair site. (*Above*) A loose repair or a repair with gapping should always be avoided. (*Center*) Tension-free repair is not an ideal repair. (*Below*) With tension in the repair site, certain bulkiness is always not avoidable. With proper pulley venting, an increase in the repair site diameter by one-fifth to one-fourth is tolerable. This degree of tension is necessary to ensure no gapping at the repair site in early active digital flexion. Ensuring tension should not be traded for decreasing the bulkiness.

usually causes 10 to 20 percent shortening of the tendon segment encompassed by the suture strands. Some surgeons allow an increase to over 150 percent of the tendon diameter after repair, but I usually avoid this degree of bulkiness.

DIGITAL EXTENSION-FLEXION TEST

In practice, if a surgeon fulfills the above-mentioned key points, there should be no need to perform a digital extension-flexion test after repair. However, this test can serve as a quality control, and I suggest it be performed after all digital flexor tendon repairs. For junior and senior hand surgeons alike, this test *objectively* validates a reliable, strong repair; sufficient venting; and proper tension. The test consists of three parts (Fig. 4).[36] Parts of this test have long been practiced by some surgeons[8]; more recently, the test was proposed in response to the call for a uniform standard test after a tendon repair.

If the repair fails the test, it should be revised. For example, if gapping is noted with the digit fully extended, the repair should be strengthened

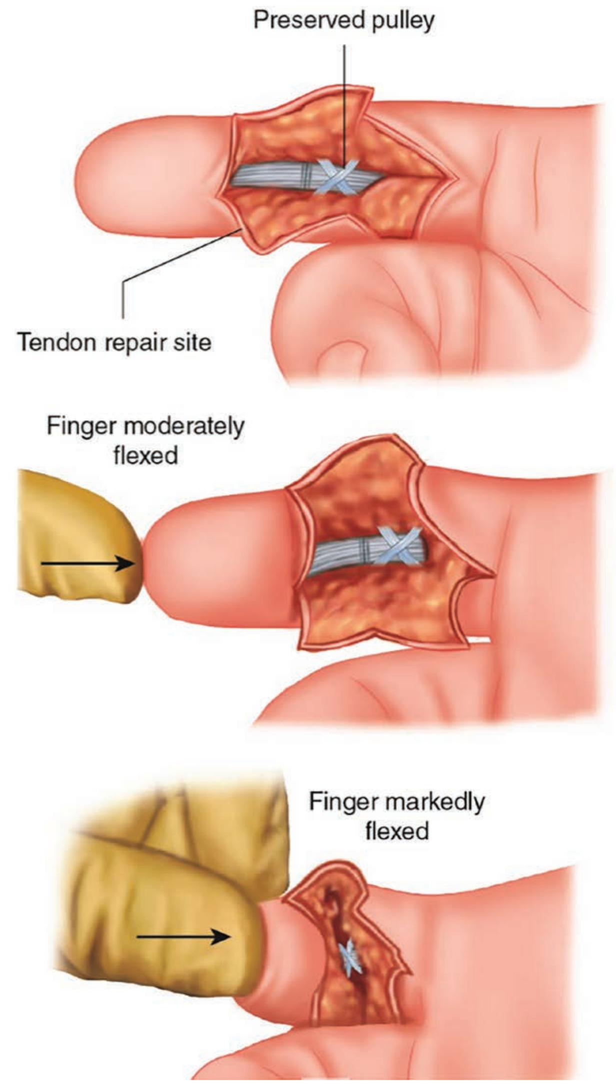

Fig. 4. This test is performed immediately after completion of the tendon repair to check the quality of the repair. The test consists of three parts: part I, passive full extension of the digit to ensure the tendon repair site shows no gapping (*above*); part II, passive flexion of the digit to confirm that gliding is smooth (*center*); and part III, pushing the digit to almost full flexion to check whether the tendon repair site (usually a bit bulky) impinges against the edge of the sheath or a pulley (*below*).

with additional core or peripheral sutures; if a pulley is found to block gliding of the repair site, the pulley needs further release. Any repair that gaps, fails, or gets stuck during finger motion during surgery risks rupture in early active digital motion, which plainly is the reason for performing such a test.

Tendon repair under wide-awake settings, as advocated by Higgins et al.[8] and Lalonde,[9] allows active digital extension-flexion (Fig. 5), which is an even more powerful validation of quality of

Fig. 5. Testing quality of tendon repair in the wide-awake setting: active extension (*above*) and active flexion (*below*) to ensure no gapping at the repair site and smooth active tendon gliding after repair of the middle finger.

Video 2. Supplemental Digital Content 2, which demonstrates intraoperative active digital extension and flexion to verify quality of repair and sufficiency of pulley-venting with the patient under local anesthesia and no tourniquet, is available in the "Related Videos" section of the full-text article on PRSJournal.com or, for Ovid users, at ***http://links.lww.com/PRS/C772***.

repair and a major advantage of the wide-awake setting.[29,30] (**See Video, Supplemental Digital Content 2**, which demonstrates intraoperative active digital extension and flexion to verify quality of repair and sufficiency of pulley-venting with the patient under local anesthesia and no tourniquet,

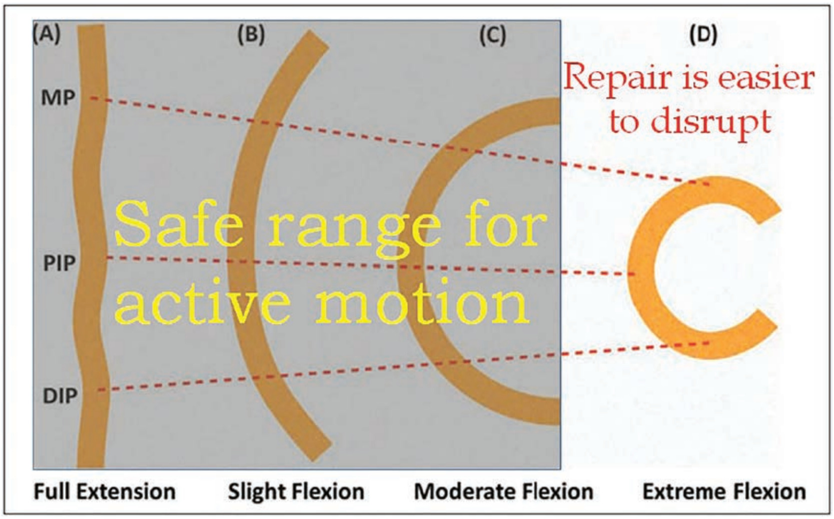

Fig. 6. Changes in resistance during active range of digital flexion from full extension. The tendon is easiest to disrupt at maximal flexion of the finger (*right*) when the tendon is bent. The safe range of active motion is from full extension to slight or moderate active flexion (*left* and *center*). *MP*, metacarpophalangeal; *PIP*, proximal interphalangeal; *DIP*, distal interphalangeal.

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COMBINED PASSIVE-ACTIVE MOTION WITH A SHORTER SPLINT

Increasingly, much shorter splints are used for protection of the wrist and hand after flexor tendon repair.[10,11,21] A short splint extends from either the distal forearm or the wrist to the fingertips; I use a splint from the distal forearm to the fingertips. In addition, exact wrist positions are no longer considered important. The wrist can be in neutral, mild flexion, or mild extension, provided that the patient is comfortable. The splint should be slightly flexed at the metacarpophalangeal joint and be straight beyond the metacarpophalangeal joint, and should extend past the finger or thumb tip. The wrist position for splinting should avoid marked flexion (which will be uncomfortable) or marked extension (which will add unnecessary tension to the repaired tendon).

There is no need to start motion or therapy in the first 3 or 4 days after surgery, which also avoids pain and discomfort.[1] From day 4 or 5, at least a few sessions of digital motion exercises are necessary; the exact number of sessions should be decided by the surgeons and therapists according to preferences and the patient's condition. In each session, to lessen resistance of joint stiffness, full passive finger motion—usually 20 to 40 repetitions—should be performed before active digital flexion. Then, active digital flexion should proceed gradually. In the first 3 to 4 weeks, only one-third to two-thirds of the active motion range should be the goal. Extreme digital active flexion should be avoided, because the tendon has greatly increased resistance to gliding and the repair is more prone to disrupt when the tendon is bent and being pulled (Fig. 6).[1,28] In reality, some patients have marked swelling at this time, making full range of active motion difficult. For them, it is not possible to immediately pursue forceful, full active flexion, but full passive finger flexion and extension should always be performed. From the end of week 3 or 4, full range of active flexion is the goal. Patients having difficulty with full active flexion at week 4 or 5 may gradually achieve full flexion in later weeks, but exercise to reduce joint stiffness and prevent extension lag is very important for eventual recovery of active finger flexion.

EARLY OUT-OF-SPLINT ACTIVE MOTION

Out-of-splint active motion is encouraged as the most efficient exercise for decreasing resistance to active motion. A robust tendon repair is strong enough to permit the digit to move out of splint. A number of surgeons obtained excellent outcomes after performing out-of-splint active digital motion after finger flexor tendon

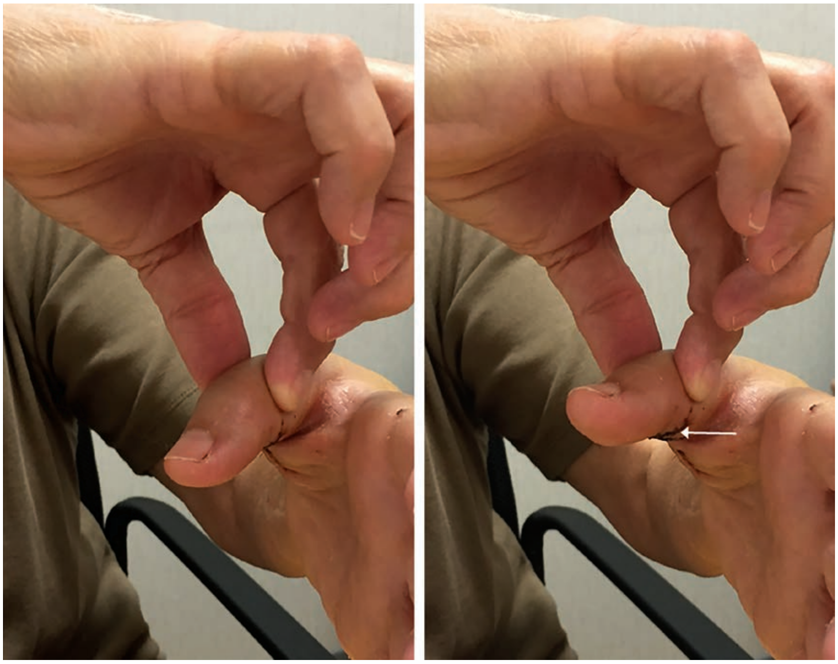

Fig. 7. Active out-of-splint motion of the interphalangeal joint with the patient's other hand holding the proximal part of the injured thumb after flexor pollicis longus repair. (*Left*) Flexion exercise. (*Right*) Extension exercise (*arrow* indicates the flexor pollicis longus cut level).

repair or flexor pollicis longus tendon repair (Fig. 7).[14,16,21]

The splint can be discarded entirely at week 6 to 7 depending on the severity of injury. Rehabilitation should continue for at least 8 to 10 weeks (or longer), with the goal of decreasing residual extension lag or achieving full flexion. After flexor pollicis longus repairs, active thumb flexion exercise is similar to that of the fingers, although some details vary.[14,16]

WHAT IS NOT IMPORTANT IN PERFORMING THE REPAIR

Venting the pulleys changes the dynamics of gliding of a repaired flexor tendon, and strong repair methods increase repair safety. Because of these measures, practices are evolving: (1) peripheral sutures can be rather sparse or even absent[14,21,22]; (2) a slightly bulky repair site is fine; (3) sheath closure is no longer considered essential or necessary; and (4) wrist positioning can be flexible, and the wrist may not even need protection. In addition, not repairing the flexor digitorum superficialis tendon (e.g., leaving the retracted flexor digitorum superficialis stump alone without resection or resection of the flexor digitorum superficialis tendon exposed in the surgical field locally) is not detrimental to finger motion.

The timing of surgery is not important if the repair is not delayed too long. Although primary repair is always preferable, delayed primary repair within 1 to 2 weeks after injury gives outcomes quite similar to those of a primary repair. Very delayed primary repair (>3 or 4 weeks after injury) can also be attempted,[25] but conservative measures, such as using a very strong repair,[25] should be taken; and surgeons should be very experienced, because the intraoperative decision as to whether to proceed with secondary tendon reconstruction requires expert judgment.

COMPLICATIONS

Repair Ruptures

Although rupture rates of primary repairs have decreased substantially, ruptures remain a persistent complication. They occur mainly in patients whose surgeons still use a weak core suture, or have not yet updated their knowledge about the keys to performing a repair and early active motion.

Adhesion Formations

Adhesions remain a major complication, and are more frequent than repair ruptures.

Significant adhesions need surgical tenolysis 6 months after the repair or 3 months after failure to improve active range of motion. Severe soft-tissue and bone injuries or local tissue loss are factors contributing to the formation of adhesions. These complications cannot be avoided entirely with current repair techniques and rehabilitation. Although mild adhesions can be disrupted during passive or active digital motion exercises, severe injury to and edema of the hand cause formation of restrictive adhesions, often requiring tenolysis. There are no recent reports on rates of tenolysis, but they are estimated to be around 10 percent.

Joint Stiffness

Although only some patients need release of joint stiffness, the incidence of joint stiffness is very high. The stiffness improves, although patients often complain of lack of full extension or flexion in the first few months after primary repair. In my experience, unless such lags are severe, it is not necessary to proceed to surgical release. The stiffness usually resolves in 5 to 6 months through daily hand use. The improvement in hand function can be observed for more than 1 year, with major decreases in extension and flexion lags.

FURTHER PEARLS IN SURGERY AND REHABILITATION

The following pitfalls and pearls are very helpful in performing primary flexor tendon repair and rehabilitation:

1. Always create a window to find a retracted proximal tendon. The proximal tendon stump usually retracts to the proximal end of the fingers or palm. Surgeons should create a separate incision in the palm to deliver the tendon end through the preserved sheath and pulleys to approximate the distal end. With flexion of the distal joint(s) of the finger, the distal tendon end can glide out to the surgical field for repair. Avoid making a lengthy sheath-pulley opening to find the retracted proximal tendon.
2. Asymmetric arrangement may be more beneficial compared with symmetric arrangement of the core sutures. This is a very recent pearl for making a core suture more resistant to gapping.[37] This practice has attracted attention from surgeons and investigators.[31]
3. Allow venting of more pulleys or aggressive motion. Pulley venting is key to decreasing tendon gliding resistance. Some surgeons perform a slightly wider pulley release and find that it makes the repair easier and tendon gliding better.[32] In addition, more aggressive motion, such as discarding or part-time use of splint protection as early as at week 5 or 6, is currently attempted by surgeons, with no increases in repair rupture.

FUTURE PERSPECTIVES

Based on recent reports and the experience of the author and his colleagues, multistrand repair, especially a six-strand core suture, ensures a strong tendon repair and almost completely prevents repair rupture. Rupture was noted only in rare patients who returned to unrestricted hand use too soon or who suffered accidents. It appears that venting the sheath-pulley a bit longer than previously recommended is not harmful and appears to cause no problems of tendon bowstringing. Although the length limit of the venting apparently varies among fingers and hands of different sizes, the A2 and A4 pulleys should certainly not both be vented. A report from Japan describes venting the entire A2 pulley in some cases.[32] Other surgeons vent the A2 pulley according to intraoperative active motion; they do not emphasize keeping it intact.[8,29,33] Considerable variations exist in clinical repair configuration; their strengths vary.[38] The best practice for pulley venting in the thumb is poorly defined, remaining a topic of discussion.[14,16,39]

Out-of-splint motion from the very initial weeks is another step toward true active motion. A common impression among many surgeons who use strong repairs and vent the pulleys is that early active motion can be more aggressive than currently recommended. In fact, if a too-forceful grip is avoided, any active motion appears to be safe. I consider that expertise of surgeons should be described together with outcomes,[36,40–42] and more aggressive pursuit of tendon motion is likely to become a future direction for research.

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CODING PERSPECTIVE

Coding perspective provided by Dr. Raymond Janevicius is intended to provide coding guidance.

The following CPT codes are reported for flexor tendon repairs in the hand.

26350	Repair or advancement, flexor tendon, not in zone 2 digital flexor tendon sheath (e.g., no man's land); primary or secondary without free graft, each
26352	Repair or advancement, flexor tendon, not in zone 2 digital flexor tendon sheath (e.g., no man's land); secondary with free graft (includes obtaining graft), each tendon
26356	Repair or advancement, flexor tendon, in zone 2 digital flexor tendon sheath (e.g., no mans land); primary, without free graft, each tendon
26357	Repair or advancement, flexor tendon, in zone 2 digital flexor tendon sheath (e.g., no man's land); secondary, without free graft, each tendon
26358	Repair or advancement, flexor tendon, in zone 2 digital flexor tendon sheath (e.g., no man''s land); secondary, with free graft (includes obtaining graft), each tendon
26370	Repair or advancement of profundus tendon, with intact superficialis tendon; primary, each tendon
26372	Repair or advancement of profundus tendon, with intact superficialis tendon; secondary with free graft (includes obtaining graft), each tendon
26373	Repair or advancement of profundus tendon, with intact superficialis tendon; secondary without free graft, each tendon

The flexor tenorrhaphy codes are global and include the following:

- Extension of wound.
- Exploration of wound.
- Débridement.
- Retrieval of tendon ends.
- Tenorrhaphy, including core and epitenon sutures.
- Straightforward wound closure.
- Application of splint.
- 90 days of postoperative care.

CODING PRINCIPLE: Accurate documentation in the operative report is crucial for precise CPT and *International Classification of Diseases, 10th Revision*, coding. The operative report must include the following:

- Which tendon (flexor, extensor, intrinsic).
- Location of injury (forearm, wrist, hand, finger, zone 2).
- Which digit, even for forearm repairs (e.g., flexor digitorum sublimis of right ring finger).
- Laterality (right or left).
- Procedure performed (primary, secondary, use of tendon graft).

Although the body of the operative report may include this information, it should always be summarized in the "Findings" section of the operative report heading.

Disclosure: Dr. Janevicius is the president of JCC (janeviciusray@comcast.net), a firm specializing in coding consulting services for surgeons, government agencies, attorneys, and other entities.

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